

Wiper System Dynamic Forces: from the Test Bench to the Vehicle

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ABSTRACT

Acoustic comfort inside the vehicle is required whenever a wiper system is in function: front wiper motor noise is of great influence on the global comfort and its perception inside the car is 100% due to transmission of vibrations through wiper system fixation points on the vehicle. As any active source, both car manufacturer and system supplier need to be involved, at early stages of project development, in order to master the vibroacoustic integration of the system into the vehicle.

This paper presents an experimental methodology dedicated to the front wiper system that offers the possibility to estimate the acoustic comfort inside the vehicle during project deployment phase, when modifications can still be proposed. Based on the XP-R-19701 standard, the procedure allows to measure, on a bench, the dynamic forces transmitted via the fixation points and details how to transpose them to the vehicle, taking into account the different specificities of the wiper system. Using a time recording of these dynamic forces and knowing the transfer path of the vehicle, the sound pressure inside the cabin can be estimated through various cycles and replayed by the car manufacturer.

This methodology is a powerful tool that allows both car manufacturer and supplier to design the sound of the wiper system and can lead to accurate specifications for the wiper system supplier at very early stages of project.

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INTRODUCTION

To set the sound quality of a system, car manufacturer deploys end-user specifications that fulfill the customer expectations. In many cases, the supplier specification for the wiper system is a characterization of the electric motor alone. Experiences have shown that this part specification cannot be linked to the end-user specifications because the wiper motor is characterized in a non-realistic manner. This part specification can lead to acoustic integration problem inside the vehicle at the end of the project, when it's very difficult to modify the system or the vehicle because the production tools have already been made.

The standard XP-R-19701, through the TPA method, allows us to create a specification at the interface of the wiper and a host structure at earlier stage of the project. This host structure can be a bench; the acoustic performance inside the vehicle can be estimated knowing the vehicle dynamic characteristics (see [Figure 1](#))

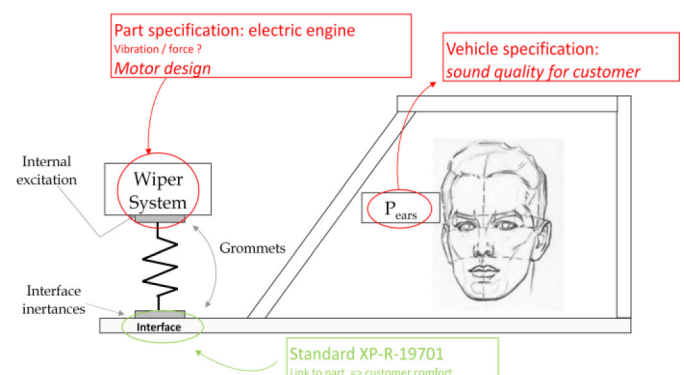


Figure 1. Front wiper system acoustic integration

In this way, the supplier specification will allow to do preventive actions at earlier stage of the project that have a direct impact on the customer expectations. In this paper the works done to build this specification for the wiper system is presented.

First, the noise excitation of the wiper system will be defined and then, according to the project chronology the objectives of this methodology will be presented. In the following theoretical part, using XP-R-19701 standard and A.T. Moorhouse's coupled system equation an adaptation that respect the wiper system specificities is written. To finish, using results of a former application the new methodology has been validated using time domain post-processing. The limitations of this methodology and the perspective are presented in the conclusion.

INTEGRATION OF A WIPER SYSTEM IN THE CAR

Wiper Motor Noise

The wiper motor consists in an electromagnetic part and a gear part. Its speed depends on the applied load. The motor vibrations include tonal components which frequencies depend on the motor and gear geometries.

The motor is mounted on a linkage, which transforms the rotating movement into a semicircular movement of two output shafts. The arms and blades are mounted on these output shafts and are in contact with the windshield with a certain tip force applied by the arm springs. The rubber blade wipes the windshield. When the system is off, the wiper blades are at Park Position.

When the wiper system is activated, the wiper blades go upstroke until they are parallel to the A pillar: this phase is called upstroke phase (Figure 2). During this "upstroke" phase, the load applied to the motor varies through time, depending on the friction coefficient of the rubber on the windshield and on the position of the arm and blade versus the windshield.

Then, there is the OutWipe (OW) reversal phase, when the movement of the blade reverses and goes downstroke; during this phase, there is a shock like vibration signature on the windshield that characterizes the reversal noise. When the arms and blades go from the OW to the InWipe (IW) position, the phase is called downstroke, and there is the reversal phase at IW, before starting a new wiper cycle.

The angle at one linkage output shaft is almost a sinus through time. The four cycles according to this angle are represented in Figure 2. A wiping cycle lasts a bit more than one second in low wiping speed conditions, and around one second in high speed conditions.

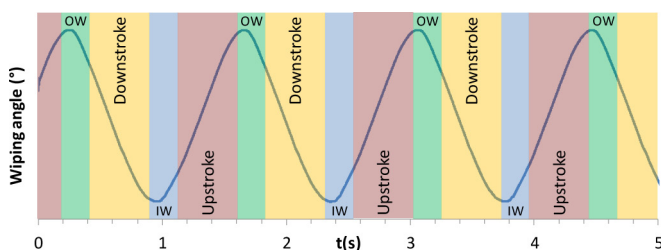


Figure 2. Output shaft angle - Wiping phases through time.

During the upstroke or the downstroke phases, the wiper motor is audible inside the vehicle due to the vibrations coming from the motor through the linkage and the grommets, via the fixation points on the car body. During these phases there is also a broadband noise created by the rubber surface wiping the windshield, which is audible inside the car, but the motor noise is perceptually recognizable by its tonal signature, and is highly linked to the perception of acoustic comfort inside the car.

In order to perform a graphic evaluation in the frequency domain, the reversal phases can be removed from the recorded signal (reversal-less signal). For that, the time signal is cut to take out the reversals; several upstroke and the downstroke phases can then be averaged in the frequency domain.

There are generally three fixation points of the wiper linkage on the car body. These points are named DS for Driver's Side, MID for Middle's Side and PS for Passenger's Side according to the Figure 3.

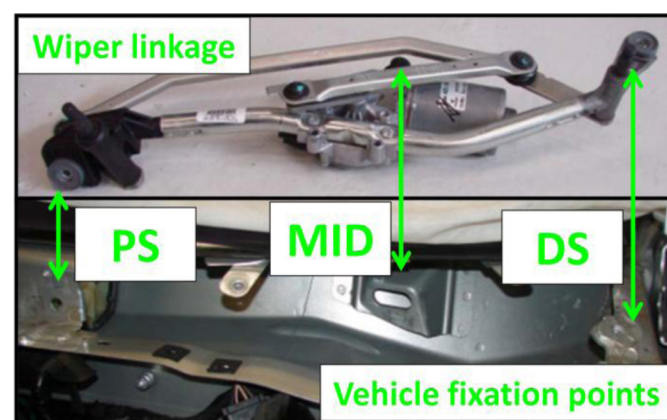


Figure 3. Valeo wiper system and vehicle fixation points

As these points can be non coplanar, their position in the space and the tip force on the arm depend on the spatial position of the linkage.

Manufacturer V-Cycle

The car manufacturer objective is to predict the sound quality of the wiper motor, as soon as possible, in the first step of the development of a new project. Generally the cycle of the development (Figure 4) contains a phase of deployment to define the expectation and specify it to the customer and a phase of validation to check the specification performance and so if the expectations are fulfilled. Today's wiper system specification doesn't allow correlating the customer specification with the expectations because it is not possible to predict the acoustic performance in the vehicle with the part specification. The goal is to make the right specification, in order to design with consistency the host structure and wiper system with an early loop of digital and physical validation.

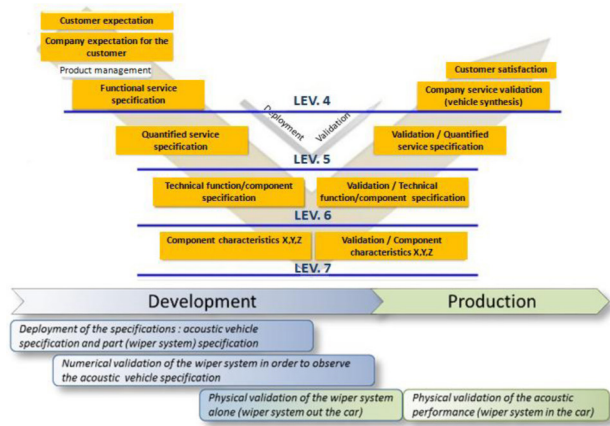


Figure 4. Renault's development cycle

OBJECTIVES OF THE STUDY

Due to the project needs, the objective is to be able to estimate the transmitted vibrations of the wiper system when the vehicle is not available. The XP-R-19701 [1] is a French standard that explains how to improve the communication between car manufacturer and system supplier in the case of an active system provided by the supplier. The philosophy of the standard is that, during the deployment phase, the supplier provides a matrix of dynamic forces at the interfaces that the car manufacturer can use to predict the annoyance inside the car. During the validation project phase, this dynamic forces matrix is then checked by the car manufacturer.

In the case of a wiper system, there are nine dynamic forces to be characterized. The matrix of these dynamic forces is described in the Figure 5.

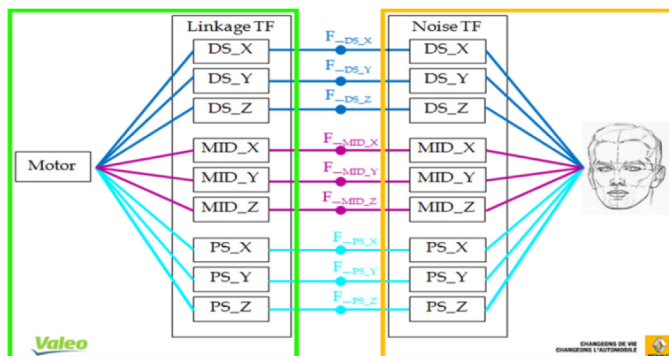


Figure 5. Wiper motor noise transfer path

According to the project phases the objectives are:

- For the deployment phase, to predict the dynamic forces when the vehicle is not available. They can be measured on a specific bench, using piezo-electric force sensors positioned in between the active and the passive structure. These sensors need a high static pre-load and are intrusive. The objective then becomes to design a bench enabling to predict dynamic forces on the car from the ones measured on a bench, knowing all the constraints of the wiper system.

- For the validation phase, to measure the vehicle's dynamic forces. As it is not possible to measure the dynamic forces on a vehicle (intrusive sensors), they can be estimated by an indirect methodology. Using measurement of accelerations near (car side) the fixation points while operating the system, and a characterization of the fixation points inertances without the system, the dynamic forces can be estimated. These tests can only be applied on a vehicle for the validation phase, which is too late in the project development for any design improvement.

To achieve these objectives the theoretical background of the coupled dynamic structure needs to be first reminded.

DYNAMIC FORCES: THEORETICAL BACKGROUND

For the deployment phase objective, the theoretical background developed in the XP-R-19701[1] is first presented together with the wiper system limitations. Then, for the validation phase objective, a methodology used to estimate vehicle dynamic forces is presented. Using this theoretical background and equations written by A.T. Moorhouse [2], a procedure that takes into account wiper system specificities is proposed.

Theory for Bench-Vehicle Transposition

Two connected structures are considered (see Figure 6): one active structure **AC** (in this case, the motor connected to the linkage), that creates vibrations due to an internal excitation and one passive structure **PC1** (in this case the car structure) that receives these vibrations via the interface. Due to the presence of a grommet at the interface, the model splits into two connections: one elastic (**e**) and one rigid (**r**) on each side of the grommet.

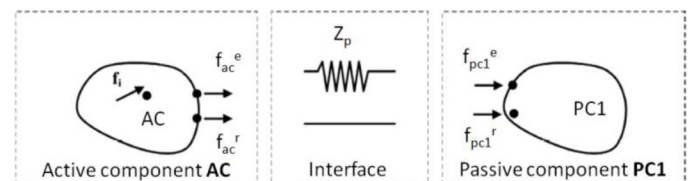


Figure 6. Connection between an active AC and a passive PC1 structure, e and r being respectively the elastic and the rigid interfaces

The force vector applied on the passive component, called f_{pc1} , is linked to the internal excitation force vector of the active component f_i by the following equation:

$$Y_{ac}^i f_i = (Y_{pc1} + Y_{ac} - \omega^2 H_p) f_{pc1} \quad (1)$$

where Y_{ac}^i is the active structure inertance matrix, Y_{pc1} the passive structure inertance matrix and H_p the interface matrix written:

$$H_p = \begin{bmatrix} Z_p^{-1} & 0 \\ 0 & 0 \end{bmatrix} \quad (2)$$

where Z_p is the dynamic stiffness matrix of the elastic connection. Concerning the rigid connection, stiffnesses are infinite so their inverses are null.

If the active structure is positioned on a second passive structure called **PC2** (in this case the measurement bench) the mathematical relationship between the internal excitation force vector and the **PC2** applied force vector will be:

$$Y_{ac}^i f_i = (Y_{pc2} + Y_{ac} - \omega^2 H_p) f_{pc2} \quad (3)$$

From the equations (1) and (3), the applied force vector of one passive structure is linked to second passive structure force vector by the relation:

$$f_{pc1} = (Y_{pc1} + Y_{ac} - \omega^2 H_p)^{-1} (Y_{pc2} + Y_{ac} - \omega^2 H_p) f_{pc2} \quad (4)$$

If **PC1** is the vehicle and **PC2** is the bench, the relationship between the two passive structures is:

$$f_{veh} = (Y_{veh} + Y_{ac} - \omega^2 H_p)^{-1} (Y_{be} + Y_{ac} - \omega^2 H_p) f_{be} \quad (5)$$

Y_{be} and Y_{veh} can be measured making excitations on the three fixation points in the three directions with an impact hammer and measuring the responses with one triaxial accelerometer positioned on each fixation points. Then a 3×3 inertances matrix can be build.

To measure Y_{ac} , the active structure should be positioned in free-free boundary conditions. This is the main issue for the wiper system because the system cannot be positioned in free-free conditions. The spring on the arms that ensures the contact of the blades on the windshield cannot be removed without changing the whole system dynamic behavior.

In this eventuality, the standard suggests four hypotheses that simplify the equation (5). Only the first one avoids the active component inertance matrix:

- Inertances of the passive structures are similar:

$$\text{If } Y_{be} \approx Y_{veh} \text{ (5) then } f_{be} \approx f_{veh} \quad (6)$$

- Both passive structures are stiff:

$$\text{If } Y_{veh} \ll (Y_{ac} - \omega^2 H_p) \text{ and } Y_{be} \ll (Y_{ac} - \omega^2 H_p) \quad (7)$$

$$\text{then } f_{be} = f_{veh} \quad (8)$$

- The vehicle structure is stiff:

$$Y_{veh} \ll (Y_{ac} - \omega^2 H_p) \quad (9)$$

$$\text{then } f_{veh} = (Y_{ac} - \omega^2 H_p)^{-1} (Y_{be} + Y_{ac} - \omega^2 H_p) f_{be} \quad (10)$$

- The bench structure is stiff:

$$Y_{be} \ll (Y_{ac} - \omega^2 H_p) \quad (11)$$

$$\text{then } f_{veh} = (Y_{veh} + Y_{ac} - \omega^2 H_p)^{-1} (Y_{ac} - \omega^2 H_p) f_{be} \quad (12)$$

For this first hypothesis, the question is to know the level of similarity that is needed.

Inverse Force Synthesis

For the vehicle validation, the force estimation can be performed using a famous methodology named inverse force synthesis. The standard also suggests this methodology. It consists in measure, γ the accelerations near the fixation points when the system operates and to characterize the inertances with the same accelerometers for the responses. The dynamic forces can be estimated with the product of the inverse inertances by the operational accelerations as described in the next equation:

$$f_{estimated} = Y_{fixation\ points}^{-1} Y_{operationnal} \quad (13)$$

This method is mainly used for complex multiple points problems but the downside is that the estimated forces are linked to the passive and the active structure.

Adaptation of Equations to Wiper Systems

Using this above background, the specific issues are:

- It is not easy to position the wiper system in free-free conditions.
- The vehicle's estimated forces cannot easily be transposed to a bench.

To deal with these wiper system specificities, coupled system equations, written by A.T. Moorhouse, can be used.

Blocked Force Methodology

The theory developed by A.T. Moorhouse is reminded in [Appendix 1](#). For this application, the main idea is that the blocked forces can be obtained using the characteristic of a coupled system according to the following equation:

$$\gamma_c = Y_c f_{bt} \quad (14)$$

with f_{bt} the blocked forces, Y_c the interface coupled inertances and γ_c the acceleration (of the coupled system) at the interface.